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# Investigation of wire EDM process parameter on kerf width for high chromium high carbon steel by response surface methodology

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## Abstract

The current work focused on studying the effect of process parameter on kerf width in Wire EDM using molybdenum wire electrode. Pulse on time, pulse off time, Servo voltage and wire feed were selected as a process parameter for design the DoE in Response Surface Methodology. It was observed that electrical parameters chosen had a significant impact on the Kerf Width. Pulse on time is the most important electrical characteristic for Kerf Width. Higher duration of the spark causes the job to shift dimensions. Utilizing Design Expert's point prediction functionality, model validation was carried out.

**Keywords:** Kerf width; Response Surface Methodology; Wire EDM; Design expert

## 1. Introduction

Wire EDM is one of the unconventional machining processes, which is mainly used to cutting of hard material like haste alloy, Inconel etc. In WEDM there is no direct contact between the wire and the workpiece. The machining behaviour is purely depends on electrical characteristics and not related to mechanical properties. The important electrical properties which influence the cutting rate is peak current, pulse on time, pulse off time, servo voltage. By varying the parameter in a certain range would certainly change the cutting rate and other outcome responses. Ramesh Kumar et.al machined the D2 steel material by considering the few important parameters like peak current, pulse on and off time. The kerf width was the assessment parameter on WEDM. Finally they concluded that the peak current has most impact on the kerf width when correlate with other parameter. [2]. Udhya Prakash et al performed machining on aluminium metal matrix composite to understand the behaviour of WEDM with the selected control variables. The MRR and SR was selected as output responses. The optimum solution was derived for the selected material with the range [3]. YasuhiroOkamoto et al observed the functionality of the multi wire EDM during the slicing of the semiconductor material. During the machining they considered kerf with as an assessment parameter. The wire feed rate effect on kerf width was finally reported in this study [4]. P. Saramah and P.K. Patawori reported the performance of WEDM on machining of Al based metal matrix composite. The analysis was done on Kerf width and MRR with the selected material. The considered parameter was pulse on and off time, Peak current. Pulse on have major influence on kerf width over others [5]. R.Calvo and M.Daniel conducted study on machining of high speed steel (HSS) AISI M42 in WEDM. The main focus was given on assessing the surface roughness of the selected steel material. The Taguchi approach was used to conduct the experiment. ANNOVA was done to predict the most influencing parameter [6]. P.Aswin and R.G Mote analysed the errors in the edge when making sharp corner In WEDM. The finite element analysis technique was employed to predict thermal effect in tip deflection [7]. R.Vijaya kumar et al preferred Response surface methodology approach to machine super alloy Inconel 625 in WEDM. The trail was done using CCD design. The Erosion rate and SR was studied with predominate factors. The different diameter sizes of wires been opted for study. The optimum result was derived through desirability analysis [8]. Ahmed A. A. Alduroobi et.al conducted experiment on AISI 1045 medium

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carbon steel to optimize the control variable in WEDM. The significant process parameter was selected and ANN technique was utilized to optimize the parameter on MRR and SR [9]. Sanjeev Kumar Garg observed the performance of WEDM during the machining of Al based MMC material. The design was effectively planned using Response surface methodology approach. The MRR and SR was Evaluated and ANNOVA was done for analysis. Genetic algorithm programme was generated using MATLAB and optimum result was derived [10]. Yasir Nawaz preferred WEDM to machine recently developed DC53 die steel. During the machining they observed MRR, SR and Kerf width with selected parameter. Response surface methodology was opted to conduct the experimental procedure [11]. M. Altin Karatas and M.A. Biberci developed a ANN model kerf width and SR for Ti-6Al-4V alloy in WEDM. Fluid pressure, servo voltage and feed rate were opted as control variable. ANNOVA test also conducted to conclude the influencing parameter [12]. Luca Watanabe Reolon et.al evaluated the performance of WEDM (kerf width & MRR) on Inconel 718 by using coated and uncoated zinc wire. The wire run off speed, pulse interval time and feed rate was considered as parameter [13]. K. Mandal et.al investigated the machinability of Al 6061 alloy using taguchi design philosophy. The MRR, Kerf width and SR was analysed. The surface properties were studied by SEM images [14]. From the extensive literature study, It found that there a need of analysing the High chromium high Carbon Die steel in die making industry. Further, the effect of process parameter like peak current , pulse on time, pulse off time and servo voltage on kerf width during the HCHCR steel is not been reported. So here an attempt is initiated to study the above said parameter on HCHCR steel using response surface methodology in WEDM is reported.

## 2. Material and methods

In this current study HCHCR steel is selected to machine in ELEKTRA SPRINTCUT 734 wire EDM machine. HCHCR steel is preferred in making of Dies for various applications. The specific properties of this material made to prefer the material in the particular domain. The application found in Thread rolling dies, Reaming tool, finishing roller for tire mills. Table 1 shows the chemical composition of HCHCR. It has been observed from the literature survey that most of WEDM studies were carried out using only a brass wire electrode. But in this study, experiments have been performed using a pure molybdenum wire as shown in Figure 1. The size of wire was measured before and after every trial experiment using a micrometre. It was observed that 0.01 mm of wire diameter is getting reduced after one hour continuous cutting operations which were conducted using fixed machining parameters.

### 2.1. Response surface Methodology

RSM (response surface methodology) is a statistical and trial technique. RSM requires a sufficient number of trial procedures information to deconstruct the problem and create numerical models for some information parameters and yield responses [10]. The needy factor is viewed as a surface to which a scientific sculpts is fitted. Four control factors are set at three levels in the current study. Along these lines, a standard central composite design (CCD) for demonstrating the Wire EDM factors for kerf width has been received. This outline includes a full factorial with 30 runs. The developed experimental DoE is shown in Table 2. Design expert 7 is used to generate the model for Kerf width. The exploratory data was subjected to an analysis of variance (ANOVA) to determine the model's behavior.

**Table 1** Chemical composition of High Carbon High Chromium Die Steel (HCHCR) (wt %)

| C | Cr | Si | V | Mn | Mo |
|---|---|---|---|---|---|
| 1.54 | 12 | 0.32 | 0.91 | 0.34 | 0.76 |

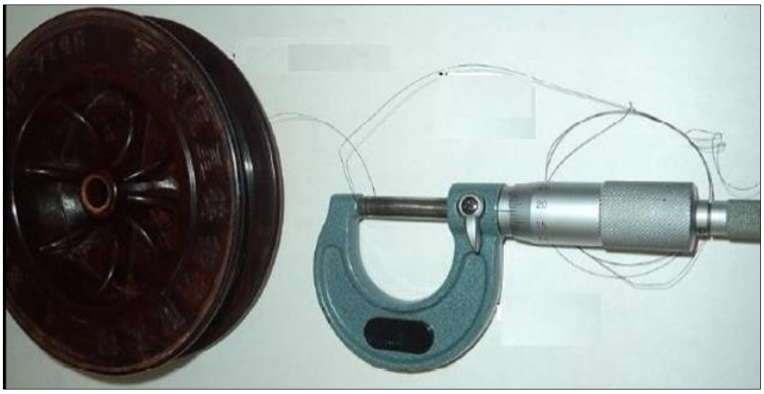

**Figure 1** Molybdenum Wire Electrode

**Table 2** Input variable and their levels

| **Variables** | **Symbol** | **Levels** | | | | |
|---|---|---|---|---|---|---|
| | | **-2** | **-1** | **0** | **1** | **2** |
| Pulse on Time- Ton (μs) | A | 105 | 110 | 115 | 120 | 125 |
| Pulse off time T-off (μs) | B | 35 | 40 | 45 | 55 | 10 |
| Servo Voltage (volt)- Sv | C | 10 | 15 | 20 | 25 | 30 |
| Wire feed rate (m/min)- Wf | D | 4 | 6 | 8 | 10 | 12 |

### 2.2. Experimental Set Up

On the four-axis ELEKTRA SPRINTCUT 734 machine, analyses were conducted to consider how control variables at different stages affect kerf the width. The sparks are produced among the work piece as well as the wire terminal. Dielectric liquid is continuously supplied between the wire electrode and work surface. The work setup is shown in the Figure 1. The minute particle generated during the machining was flushed by the dielectric medium. The size of the work plate is 90mm x 75mm x 8mm. The wire of 0.25mm diameter is used for the experimentation. The demineralized water at room temperature is used as a dielectric liquid. Kerf width is the summation of wire diameter and two times of wire workpiece gap [13,15].

$$\text{Kerf width (Kw)} = 2 \times \text{gap between wire and workpiece}$$

**Table 3** Design of experiments

| Run | Pulse on time | Pulse off time | Servo voltage | Wire feed | Kerf Width |
|---|---|---|---|---|---|
| 1 | 2.00 | 0.00 | 0.00 | 0.00 | 0.191 |
| 2 | 1.00 | 1.00 | -1.00 | 1.00 | 0.182 |
| 3 | -1.00 | 1.00 | 1.00 | -1.00 | 0.141 |
| 4 | -1.00 | 1.00 | -1.00 | -1.00 | 0.139 |
| 5 | -1.00 | -1.00 | 1.00 | -1.00 | 0.139 |
| 6 | -2.00 | 0.00 | 0.00 | 0.00 | 0.132 |
| 7 | 1.00 | 1.00 | 1.00 | -1.00 | 0.182 |
| 8 | 1.00 | 1.00 | -1.00 | -1.00 | 0.179 |
| 9 | 1.00 | -1.00 | -1.00 | -1.00 | 0.175 |
| 10 | 1.00 | 1.00 | 1.00 | 1.00 | 0.175 |
| 11 | 0.00 | 0.00 | 0.00 | -2.00 | 0.159 |
| 12 | 0.00 | 0.00 | 0.00 | 2.00 | 0.155 |
| 13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.154 |
| 14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.154 |
| 15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.154 |
| 16 | -1.00 | 1.00 | -1.00 | 1.00 | 0.152 |
| 17 | -1.00 | 1.00 | 1.00 | 1.00 | 0.151 |
| 18 | -1.00 | -1.00 | 1.00 | 1.00 | 0.151 |
| 19 | -1.00 | -1.00 | -1.00 | 1.00 | 0.149 |
| 20 | -1.00 | -1.00 | -1.00 | -1.00 | 0.145 |
| 21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.164 |
| 22 | 0.00 | 0.00 | 2.00 | 0.00 | 0.161 |
| 23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.161 |
| 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.161 |
| 25 | 0.00 | 2.00 | 0.00 | 0.00 | 0.161 |
| 26 | 1.00 | -1.00 | -1.00 | 1.00 | 0.172 |
| 27 | 1.00 | -1.00 | 1.00 | -1.00 | 0.169 |
| 28 | 1.00 | -1.00 | 1.00 | 1.00 | 0.169 |
| 29 | 0.00 | -2.00 | 0.00 | 0.00 | 0.166 |
| 30 | 0.00 | -2.00 | 0.00 | 0.00 | 0.165 |

## 3. Results and discussion

### 3.1. Effect of WEDM parameters on kerf width

Response surface charts were plotted to investigate the effect of Wire EDM parameters on kerf width, as shown in the figure. 2 & 3. The RSM chart shows that the KW increases with increasing pulse on time and Wire Feed. Increasing the pulse on time increases the discharge energy across the electrode, resulting in increased melting and evaporation of material [12]. Increased melting and evaporation, combined with a high dielectric supply, results in a wider kerf. [12,13].

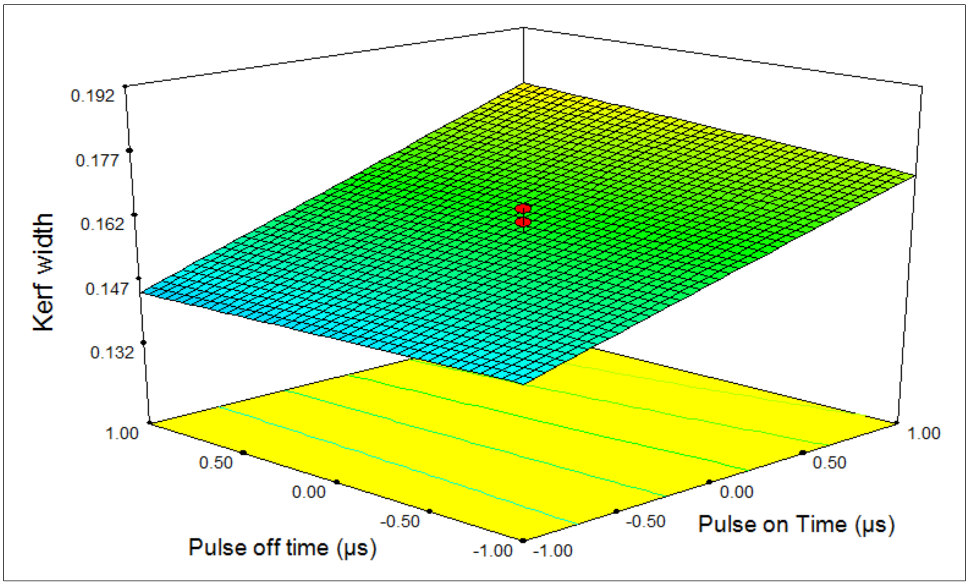


**Figure 2** KW vs Pulse on time & Pulse off time

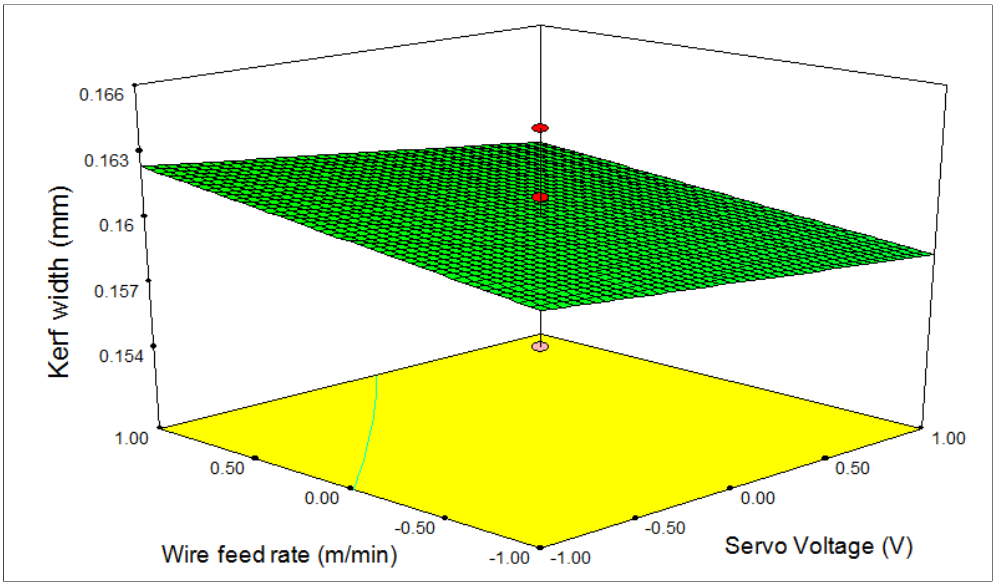


**Figure 3** KW vs servo voltage & Wire feed rate

### 3.2. Analysis of kerf width

Table 4 shows that the quadratic model's p value has a significant effect on the output response. As confirmed by ANOVA results, it is understandable that all input parameters have a significant impact on kerf width. At the same time, the kerf width increased by a percentage, when pulse on time (Ton) increased from low to high. Long pulse on time (Ton) leads to high performance in heat transfer inside the dielectric fluid and work piece, and it is capable of removing molten or liquid metal by making dielectric pressure flushing in a constant certain amount. F ratio was greater than the tabulated values at 95 % confidence level. $R^2$ and adjusted $R^2$ values are 91.70% & 88.54% respectively. The developed regression equation is shown in the equation 1.

KW =+0.16028+0.014754 * A +9.20833E-004* B-1.01250E-003 * C +1.01250E-003 * D
+2.11875E-003 * A * B-6.18750E-004* A * C+6.31250E-004* B * C+4.06250E-00 * B * D

**Table 4** ANOVA for Ker width

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 0.005381 | 8 | 0.000673 | 29.1600428 | < 0.0001 | significant |
| A-A | 0.0052245 | 1 | 0.005224 | 226.494528 | < 0.0001 | |
| B-B | 2.035E-05 | 1 | 2.04E-05 | 0.88224744 | 0.3583 | |
| C-C | 2.46E-05 | 1 | 2.46E-05 | 1.06664133 | 0.3135 | |
| D-D | 2.46E-05 | 1 | 2.46E-05 | 1.06664133 | 0.3135 | |
| AB | 7.183E-05 | 1 | 7.18E-05 | 3.1138416 | 0.0922 | |
| AC | 6.126E-06 | 1 | 6.13E-06 | 0.26556297 | 0.6117 | |
| BC | 6.376E-06 | 1 | 6.38E-06 | 0.27640116 | 0.6046 | |
| BD | 2.641E-06 | 1 | 2.64E-06 | 0.11447847 | 0.7385 | |
| Residual | 0.0004844 | 21 | 2.31E-05 | | | |
| Lack of Fit | 0.0003812 | 16 | 2.38E-05 | 1.15418702 | 0.4754 | not significant |
| Pure Error | 0.0001032 | 5 | 2.06E-05 | | | |
| Cor Total | 0.0058654 | 29 | | | | |

## 4. Conclusion

In this study to explore the kerf width on machining of High carbon and high chromium die steel were done by using Response surface methodology design. Based on these experiments the following conclusions are drawn.

- Wire feed rate and pulse on time (Ton) have significant impact on and kerf width (Kw). Kerf width is increased with increase in wire feed rate and Ton, and decreased on increase in pulse off time. .
- (ii)The maximum kerf width is observed on 125 µs pulse on time, 45 µs pulse off time, 20V voltage and, 8m/min wire feed.
- (iii)The least kerf width is observed on 105 µs pulse on time, 45 µs pulse off time, 20V voltage and, 8m/min wire feed.
- (iv)ANOVA results show that model is significant, lack of fit is not significant and pulse on time has a significant effect on kerf width rather than a other parameter

## Compliance with ethical standards

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### *Disclosure of conflict of interest*

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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